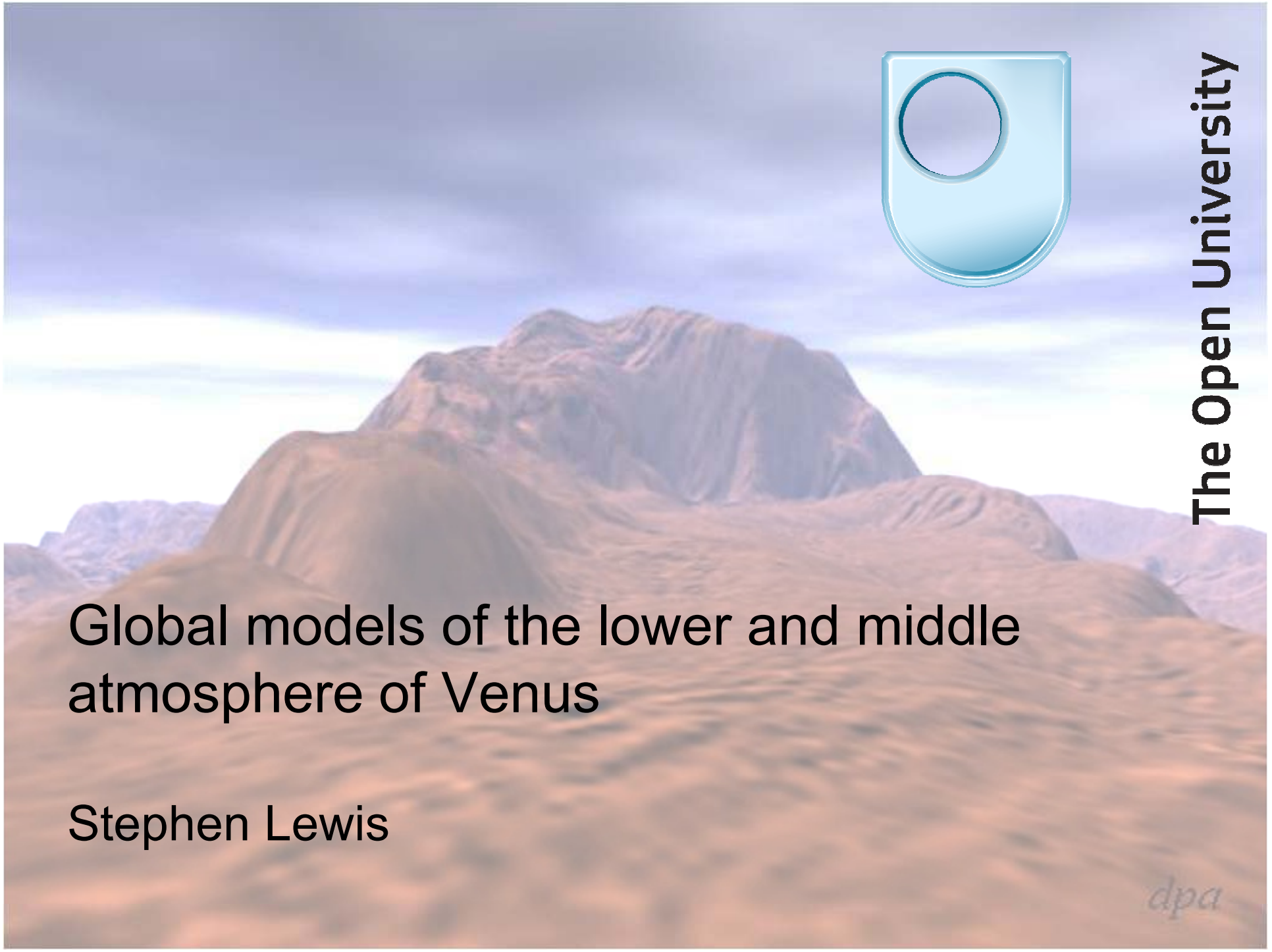
Global models of the lower and middle atmosphere of Venus

Conference or Workshop Item



Global models of the lower and middle atmosphere of Venus

Stephen Lewis

Venus atmospheric dynamics

- What are the key mechanisms responsible for atmospheric super-rotation on Venus?
  - Role of the Hadley circulation
  - Role of large-scale waves, thermal tides and small-scale turbulence
  - Role of interaction with the solid surface
- What is the nature of the polar vortices?
  - Interaction with the large-scale super-rotation
- What are the properties of the large-scale waves seen in the clouds?
- What are the radiative feedbacks from the clouds?
- What is the nature of the circulation beneath the clouds?
- How do all of these processes vary with time?

Venus global modelling – challenges

- Slow rotation rate means primary balance is cyclostrophic, not geostrophic
- Venus atmosphere is ~90 times more massive than Earth's and optically thick
  - Models have to be 'spun-up' over 50,000-100,000 days to equilibrate
  - Small residuals (and quantities which are not conserved by the dynamical cores) accumulate over model integration times giving rise to large net effects, e.g. global super-rotation, which are sensitive to model details
    - a weakly-forced system compared to Earth and Mars
- The Venus lower and middle atmosphere is poorly observed below the clouds and so models are not well constrained
- Venus is a severe test for terrestrial atmospheric models

Super-rotation in Venus GCMs

Yamamoto & Takahashi (2003)

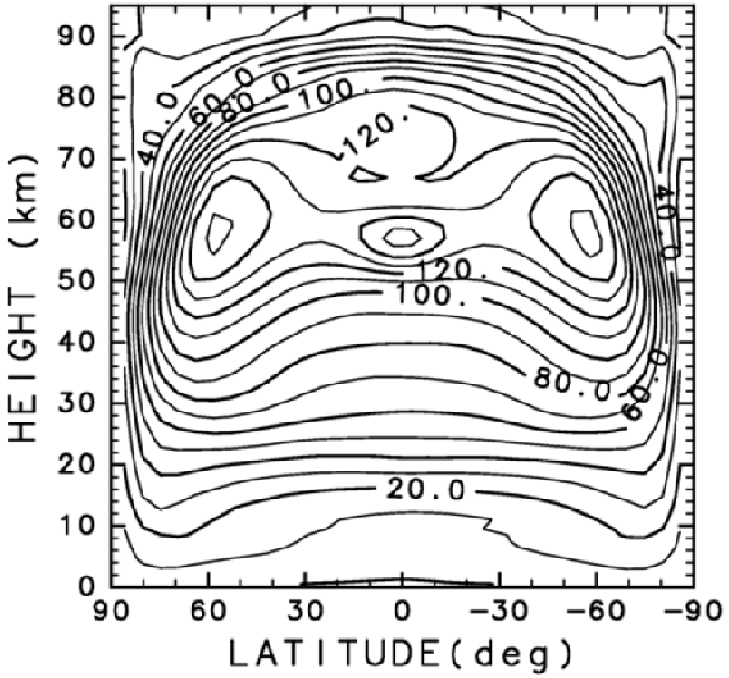


Figure 1. Latitude–height cross section of longitudinally averaged zonal flow (m s^{-1}).

Lee, Lewis & Read (2005)

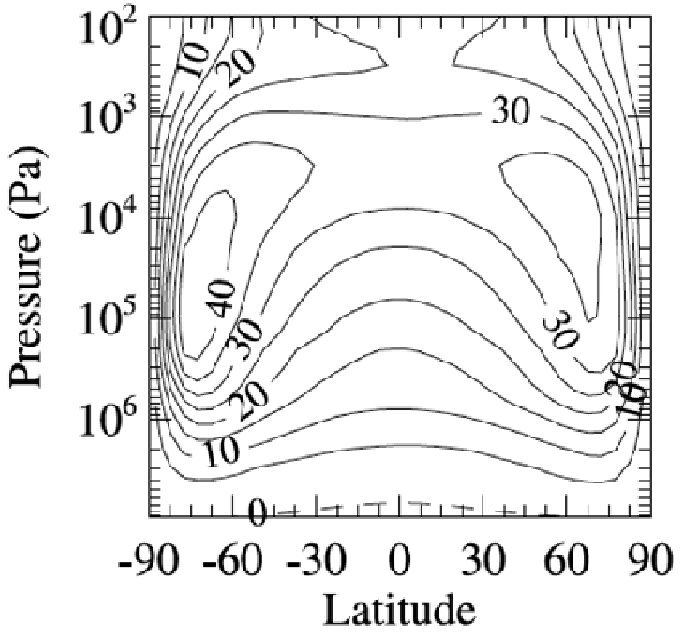
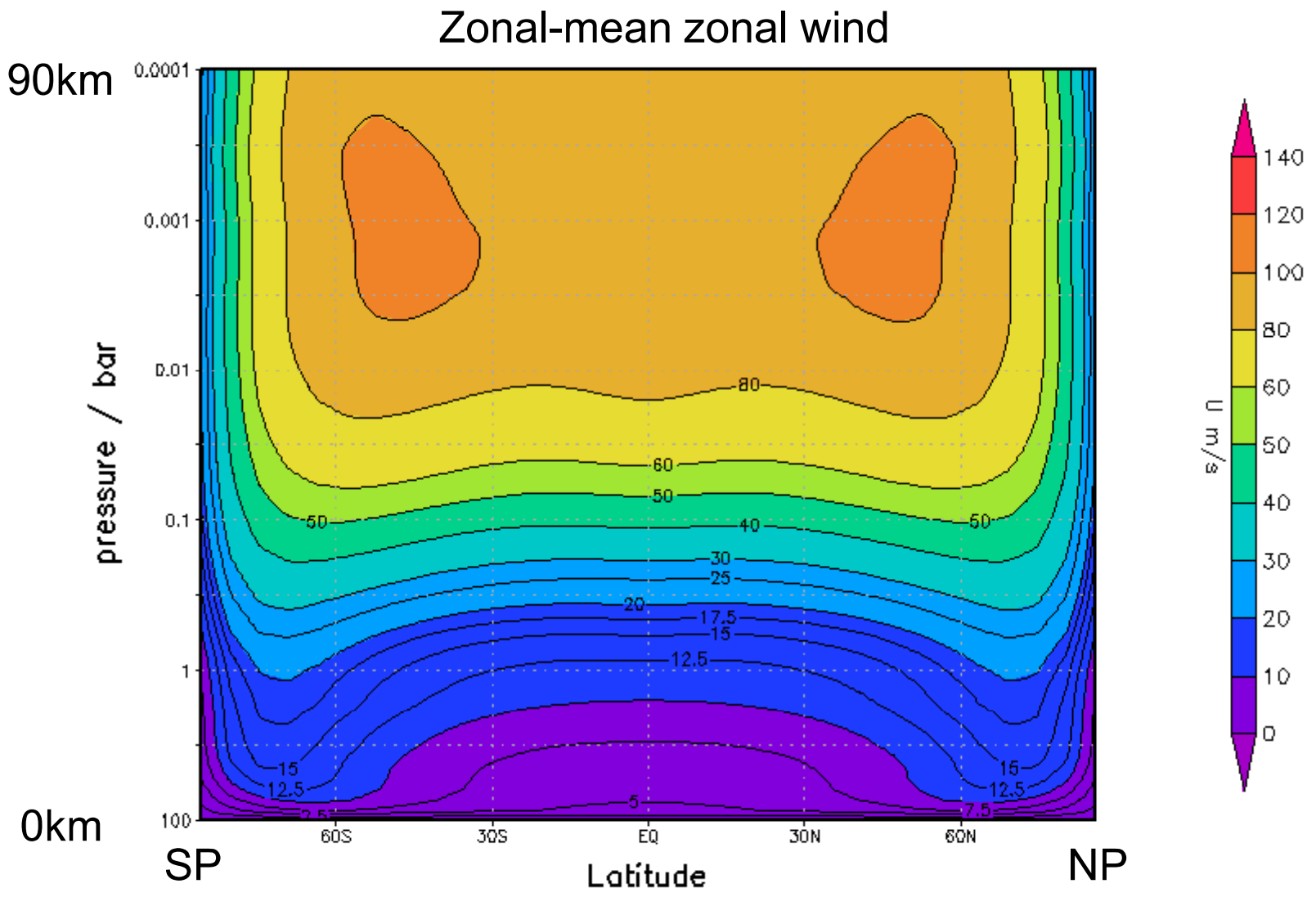


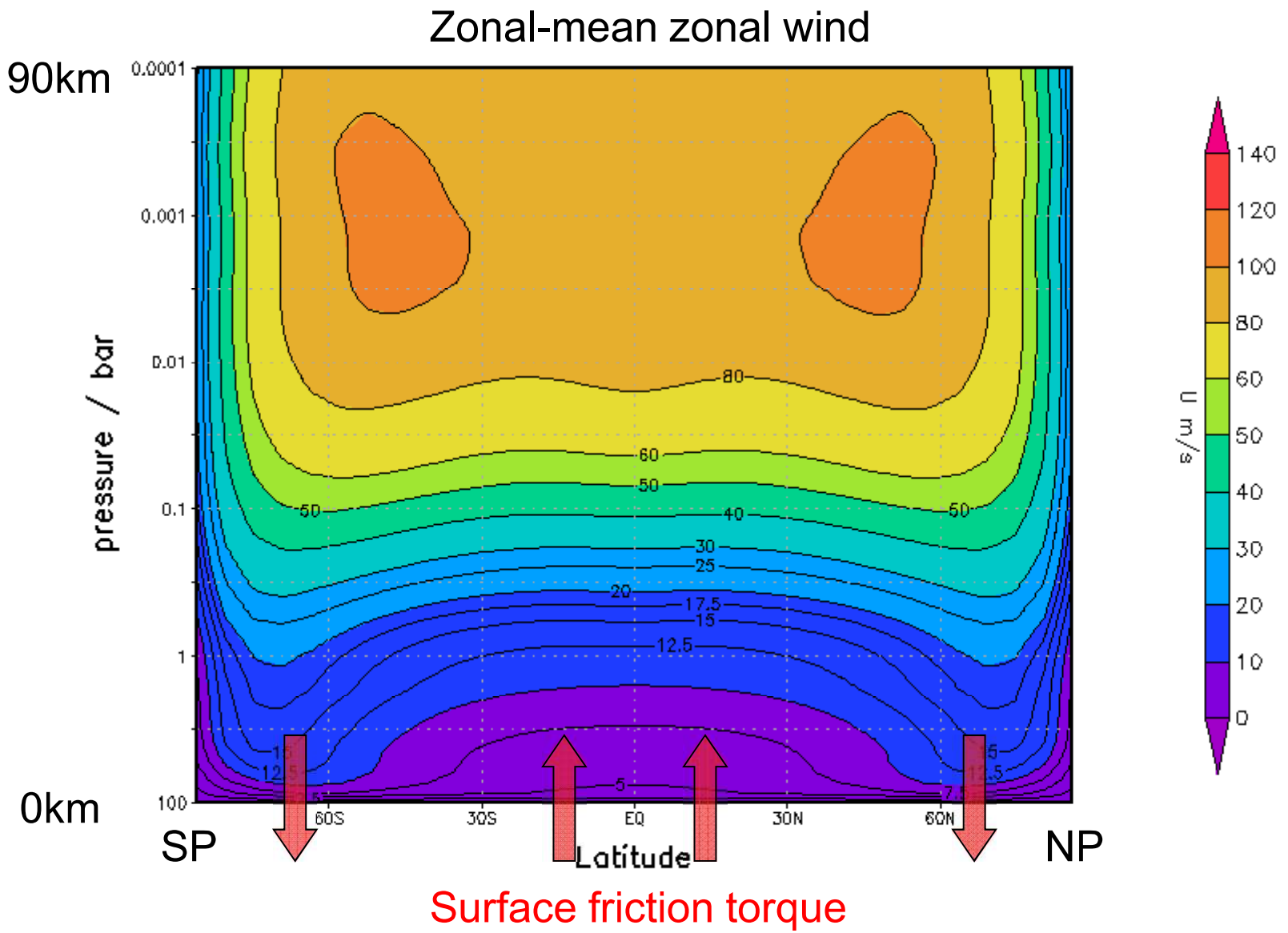
Figure 6. Latitude-height cross section of the zonal mean westward wind speed, averaged from 3 years of data at 100 years, Δ = 5 m s^{-1}.

These models may assume unrealistic thermal forcing to get realistic winds

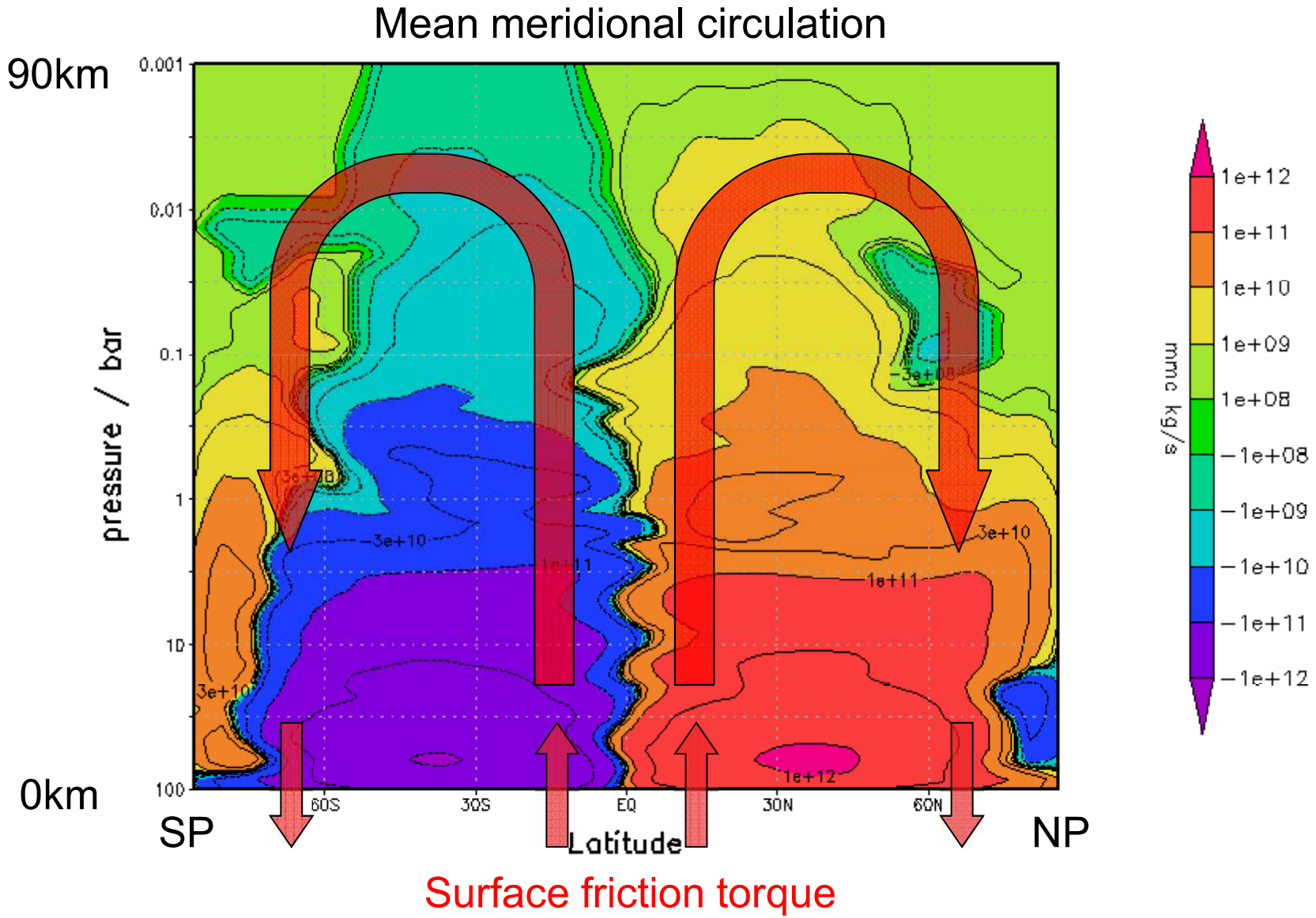
Super-rotating winds in the OU VGCM



Surface/atmosphere AM exchange

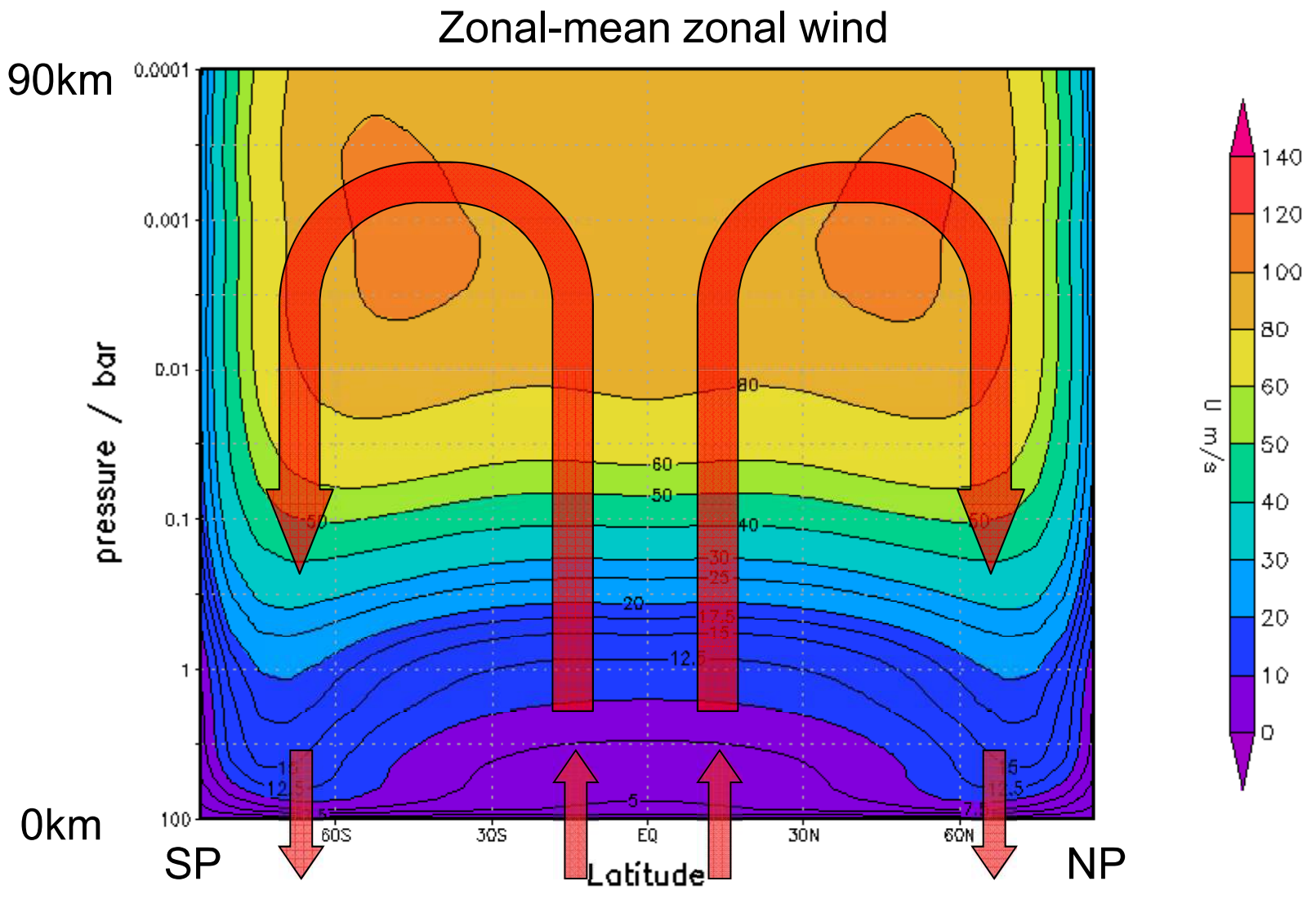


Mean meridional transport



Surface friction torque

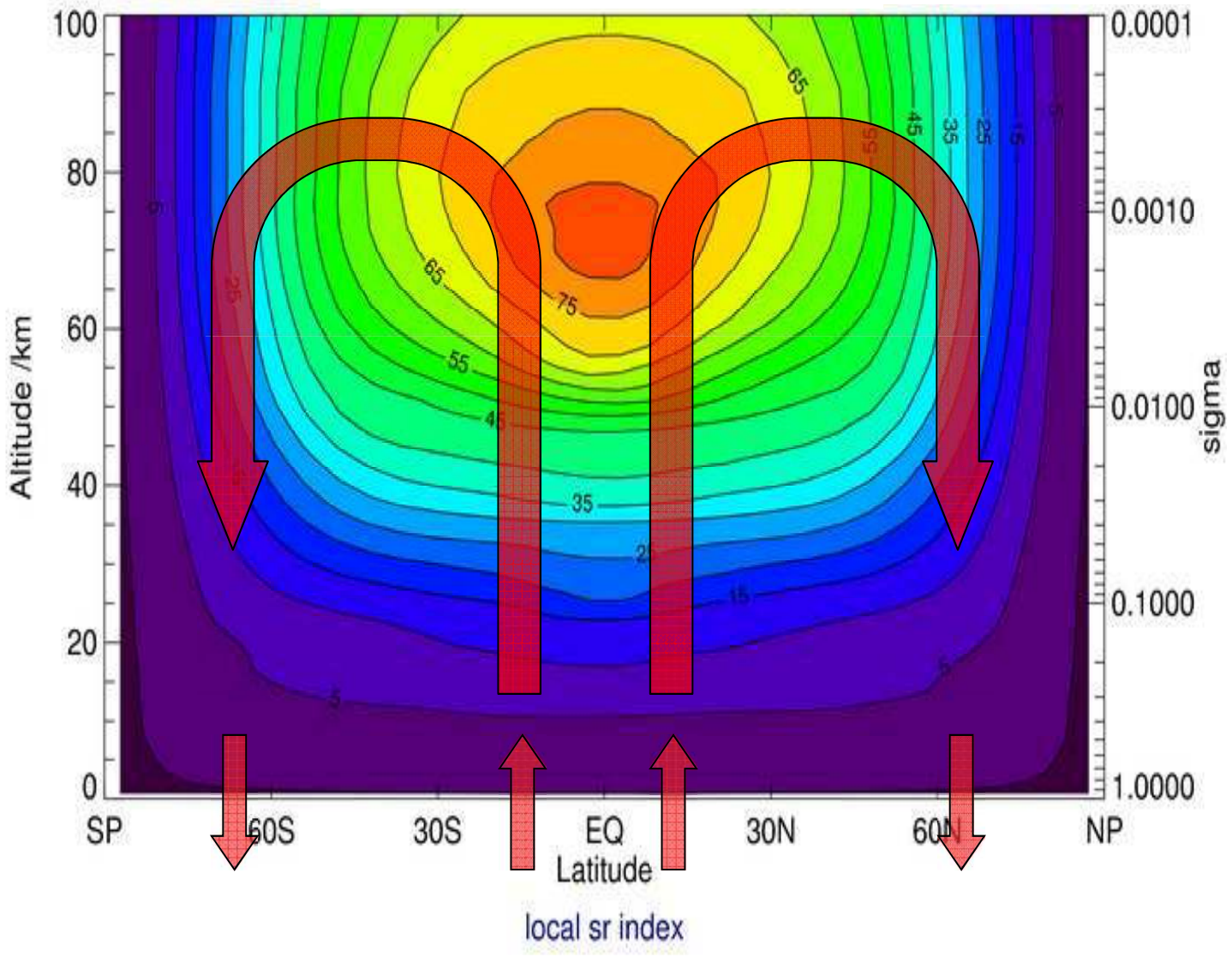
Mid-latitude prograde jets



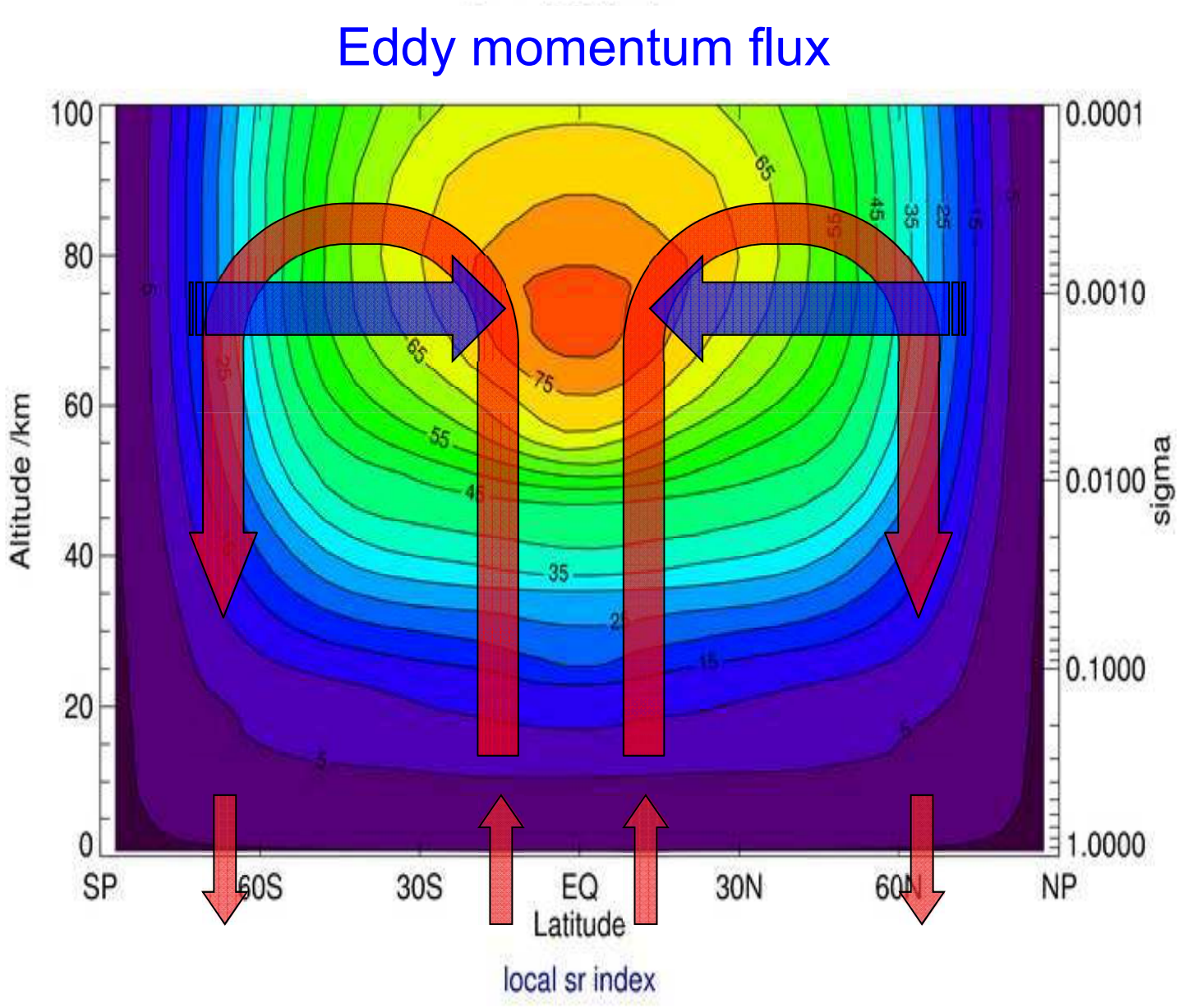
Angular momentum

$$s = \frac{m}{\Omega a^2} - 1$$

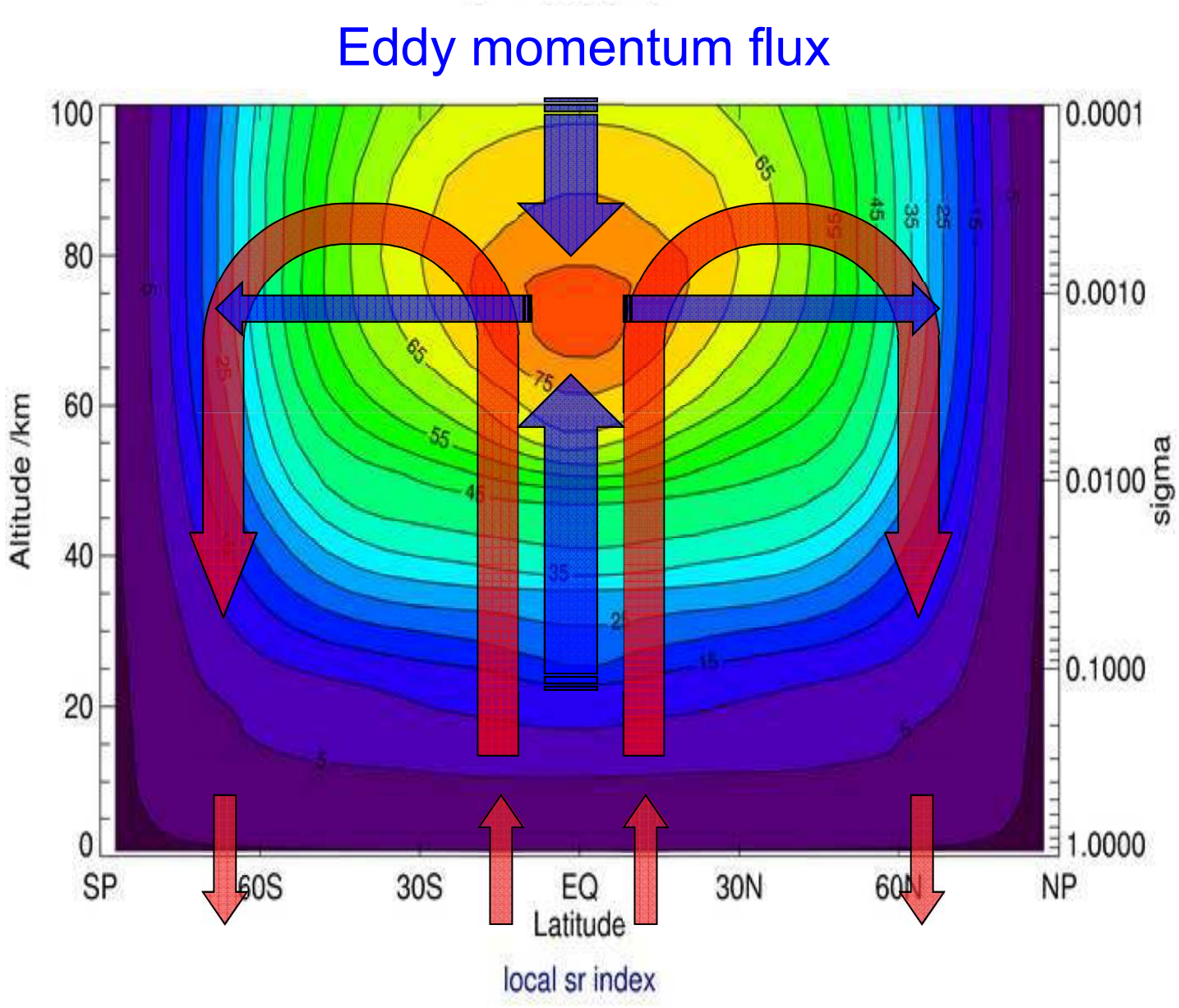
$$m = a\cos\phi\,(\Omega a\cos\phi + u)$$



Gierasch (1975)/GRW mechanism



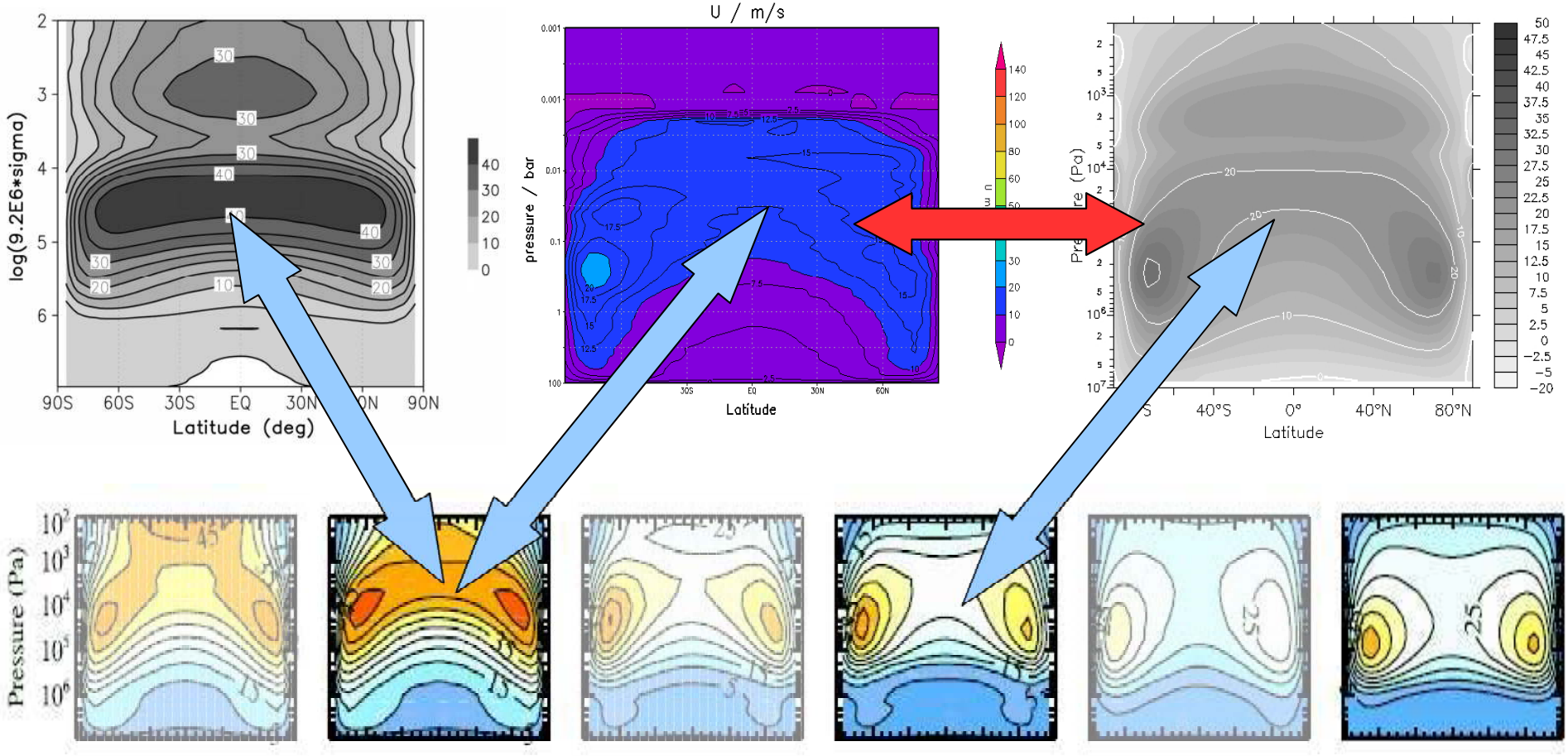
Thermal tide/QBO-like mechanism



ISSI Venus model intercomparison

Mean zonal wind field

CCSR (BS) OU (base) LMD (base)



LR10a2 LR10a1 LR10b2 LR10b1 LR10c2 LR10c1

Venus Intercomparison experiments

	CCSR	LMD	OU	Ox	UCLA	LR10
Baseline	T21L50	base	T21L50	x		
Sensitivity to vertical grid						
Vertical grid	L52		L100, L200			LR10a1,b1,c1
Sensitivity to boundary conditions						
Topography	BT / YT	x	x			
Sponge layer	ND	spg3	eddies	x		LR10a2,b2,c2
Varying PBL	BL	kzfx/clmn/MY		x		
Sensitivity to horizontal resolution						
Low resolution	T10	x	T10			
High resolution	T42	x	T42		(1°x1°)	
Sensitivity to initial state and forcing						
Diurnal cycle			x	x		
Varying initial state	Uini	Uini	Uini			

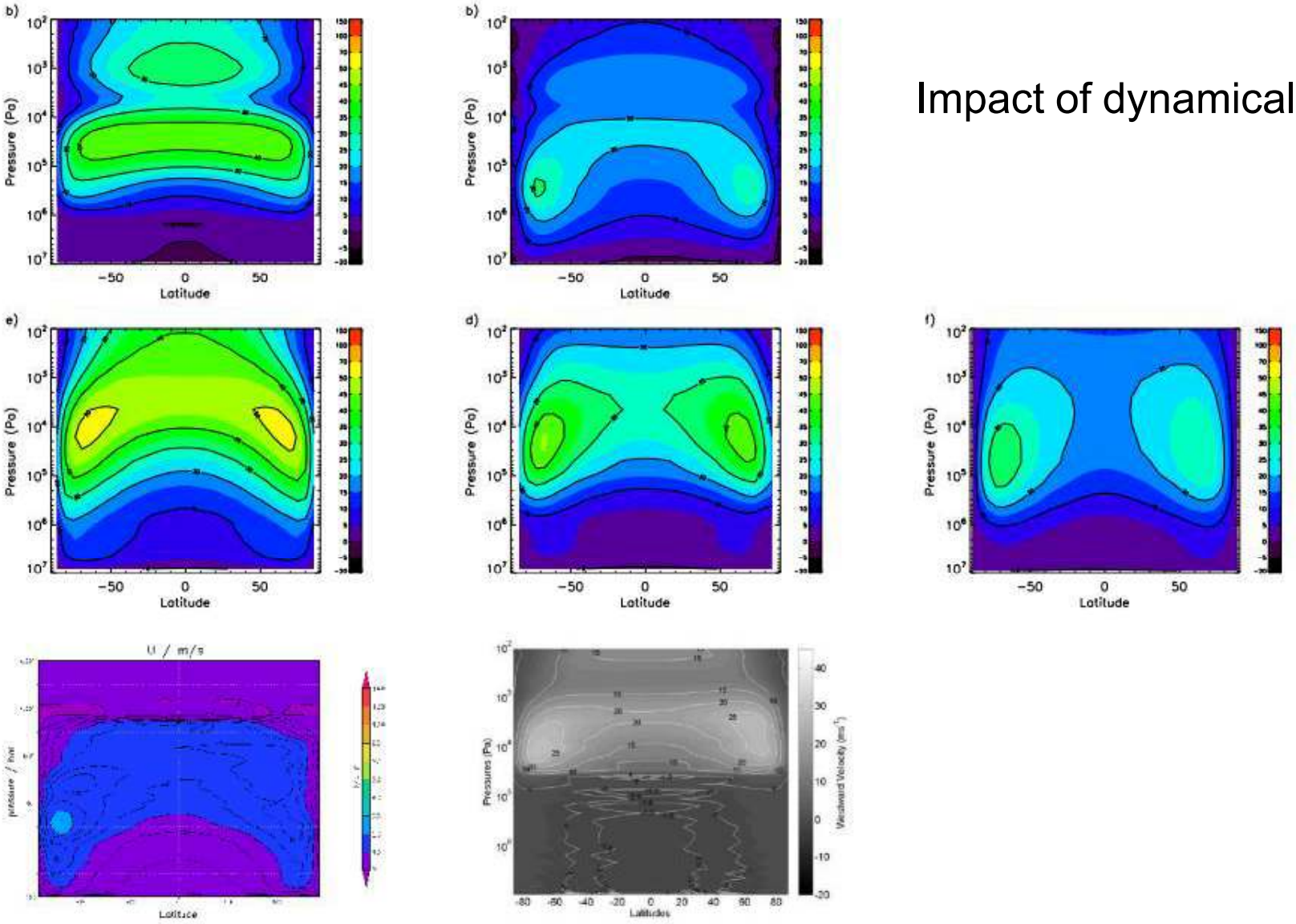
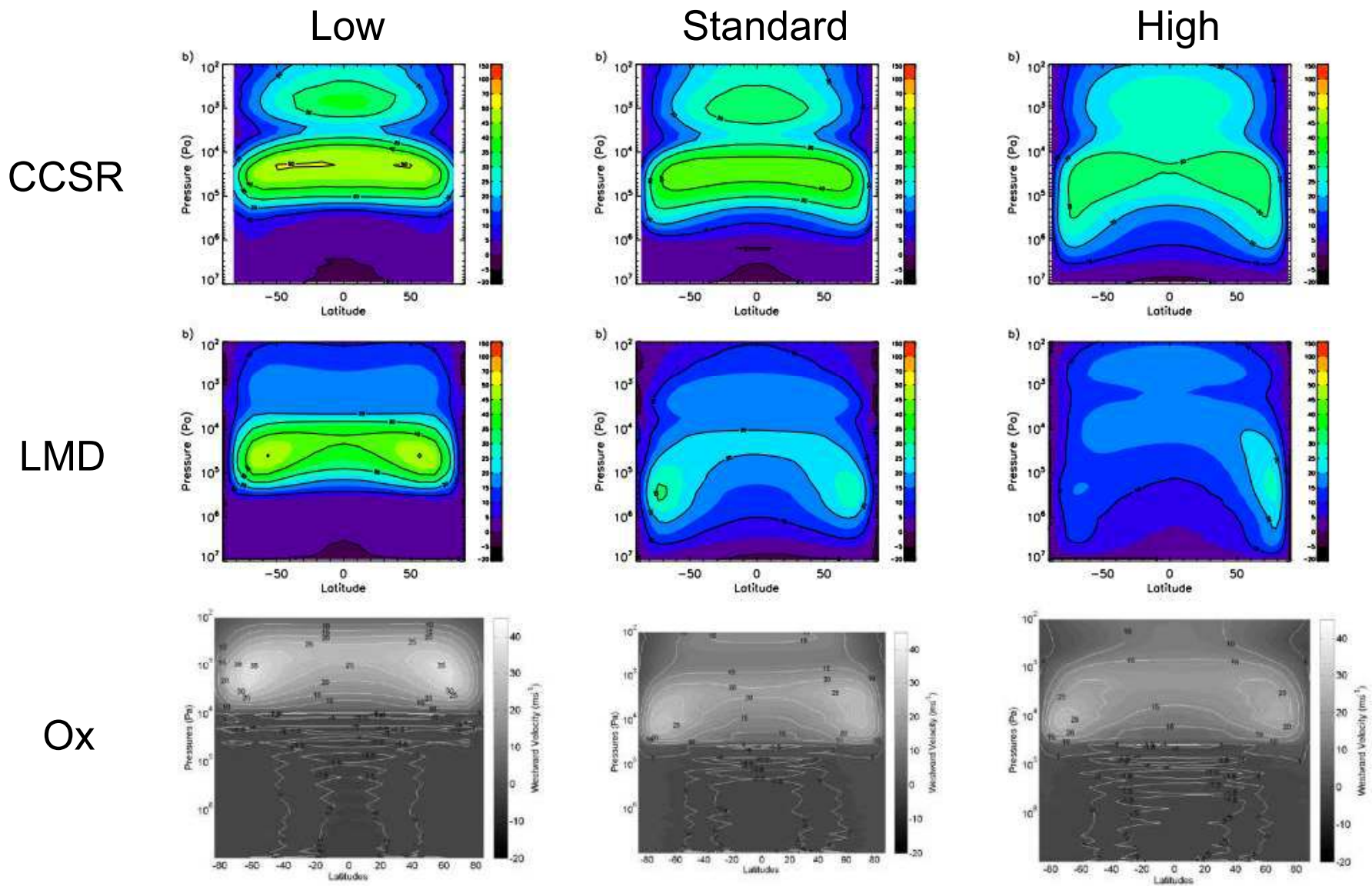
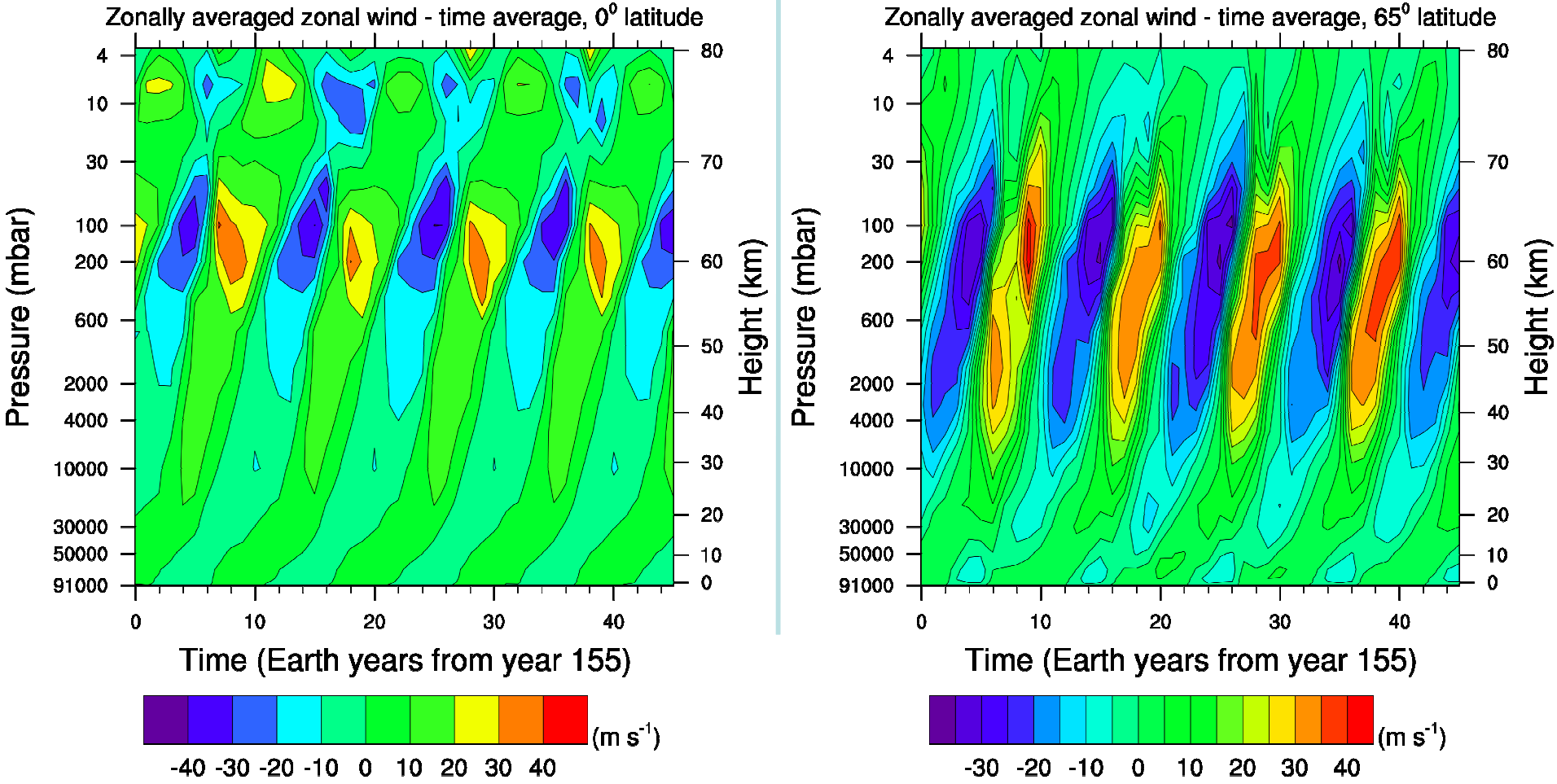


Fig. 2 Zonally and temporally averaged zonal wind fields obtained in all the baseline simulations. Unit is m/s. The first column is spectral models: (a) CCSR, (d) LR10-s, (g) OU. The second column is finite difference models: (b) LMD, (e) LR10-fd, (h) OX. The third colum is the finite volume models: (c) UCLA, (f) LR10-fv. For the UCLA simulation (c), the resolution is much higher than the other baseline runs.

Impact of horizontal resolution

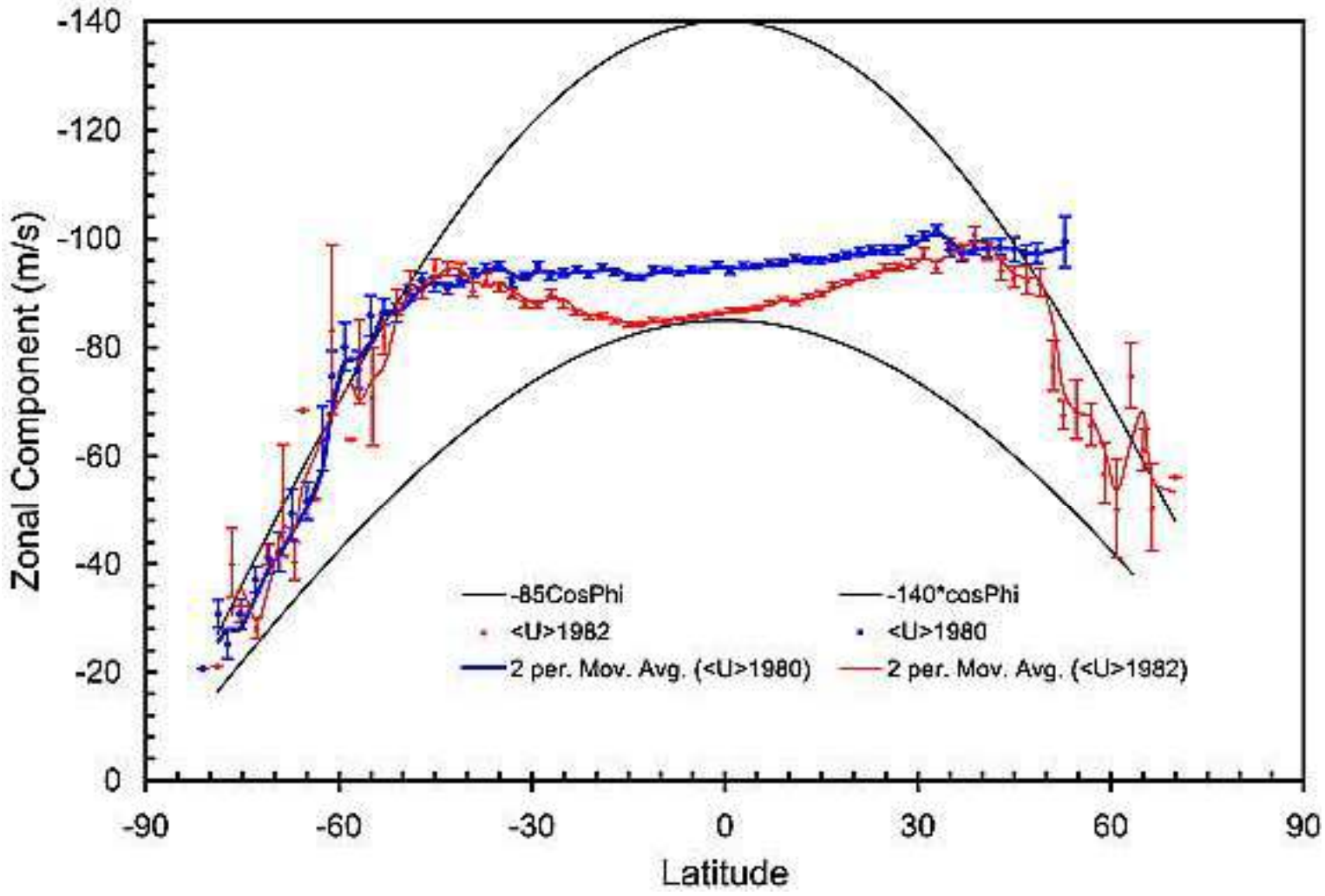


Temporal variability (Parish et al. 2010)



Parish et al. (2010)

Cloud-tracked zonal winds at ~65 km



Limaye (2007)

Summary

- Great progress in Venus global models in last decade, all capable of simulating a super-rotating atmosphere
  - Models may rely on unrealistic forcing to get wind magnitude right
  - Results are sensitive to many, poorly-known parameters
- More observations of Venus middle and lower atmosphere are needed to constrain models and processes
  - Venus Express and Akatsuki provide much new data at cloud level and above
- Venus provides a rigorous test of global atmospheric model dynamical cores
- Results of ISSI study to be published in “Towards understanding the climate of Venus – The application of terrestrial models to our sister planet” (Bengtsson et al., Springer, 2011)

The Open University Venus SGCM

- Simplified physics GCM similar to Yamamoto & Takahashi (2003) and Lee, Lewis & Read (2005)
- Pseudo-spectral dynamical core
  - Horizontal resolution: T10, **T21,** T42
  - Vertical resolution: 32, **50,** 100, 200 levels
  - Typical integrations ~ 70,000 days
- Linear forcing, Newtonian cooling and Rayleigh friction
  - Future plans include more detailed PBL scheme and radiation scheme shared with the Oxford VGCM
- 8^{th} order hyperdiffusion and 'sponge' in upper model levels
- Topography
- Diurnal cycle